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(54) Combined gas and steam turbine plant

(57) In a power plant which includes a gas turbine unit and a steam turbine unit which units are supplied with gas and steam, respectively, from a common combustion chamber 1, 2 in which combustion takes place under pressure in a fluidized bed 3, the units of the plant are designed to operate efficiently with each other at an ambient temperature (T_o), which is usually about +30°C. To enable the plant to be used to the maximum at ambient temperatures below T_o, when the flow of combustion air to the fluidized bed 3 increases and more fuel can be burnt, the fuel supply to the bed 3 from a container 50 via a conduit 33 is increased in dependence on the available quantity of combustion air, e.g. as measured at 53. Simultaneously the temperature of the fluidized bed 3 is regulated by injecting water or water vapour into the bed 3 from a container 34 via a conduit 35 e.g. by a transducer 38 in the combustion chamber which controls this injection of water or water vapour by regulating a control valve 36 in the conduit 35. The steam formed by the injected water or water vapour expands in the gas turbine unit together with the combustion gas and increases the power of the unit.

FIG. 2

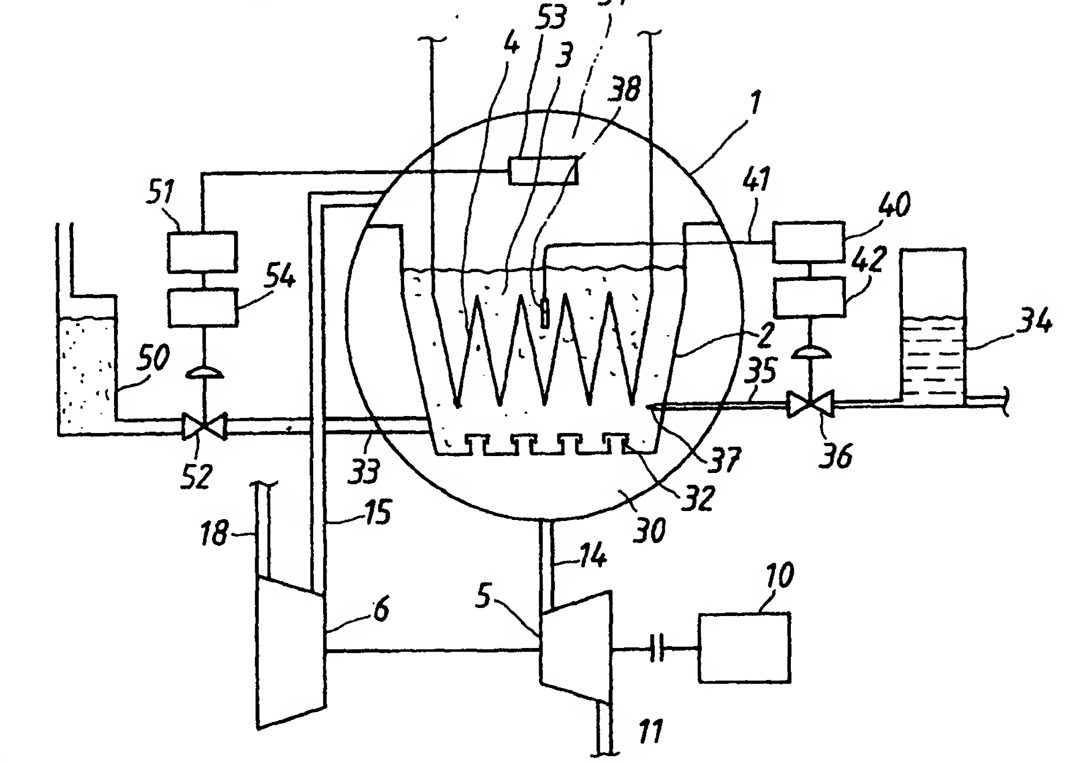

FIG. 1

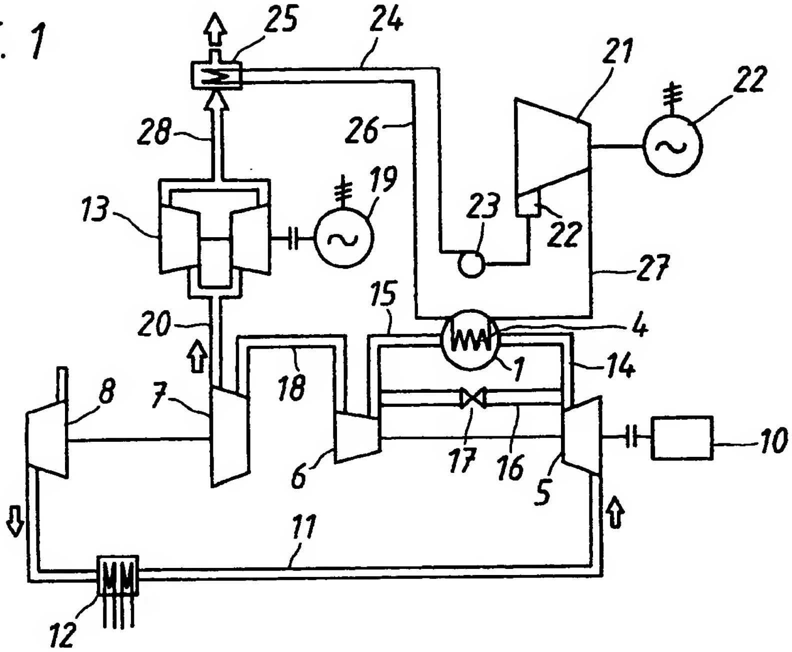
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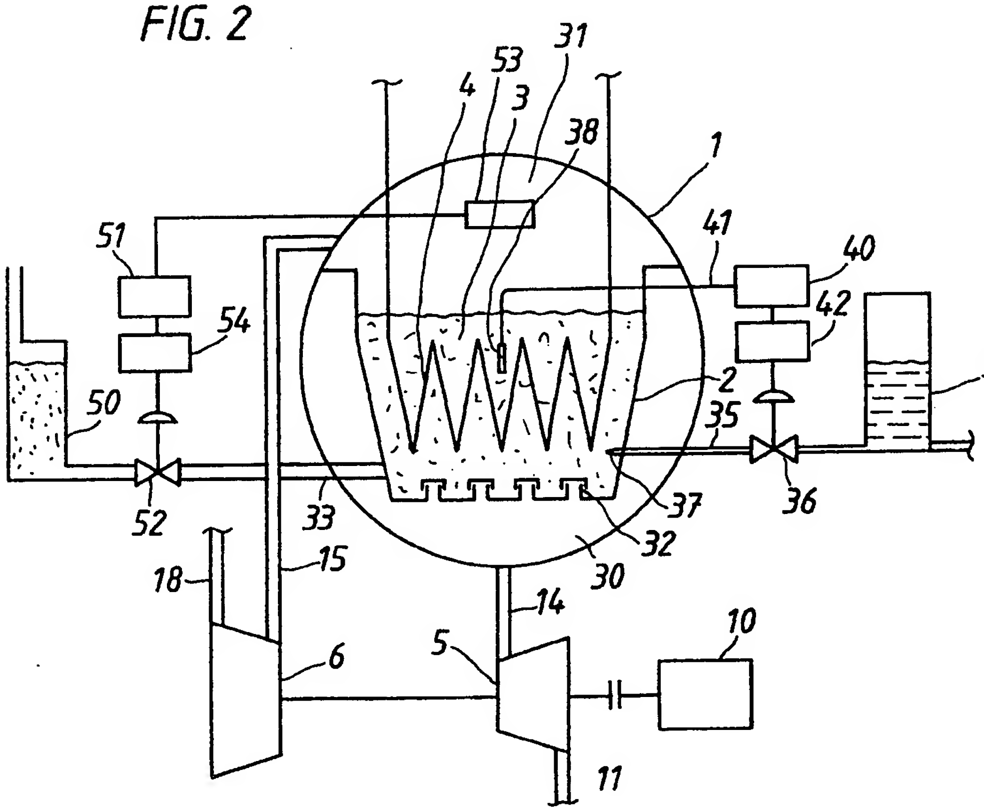
FIG. 2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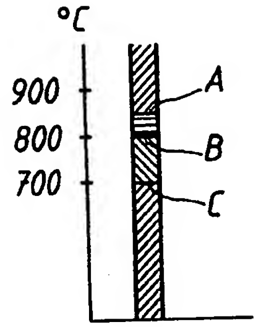

FIG. 3

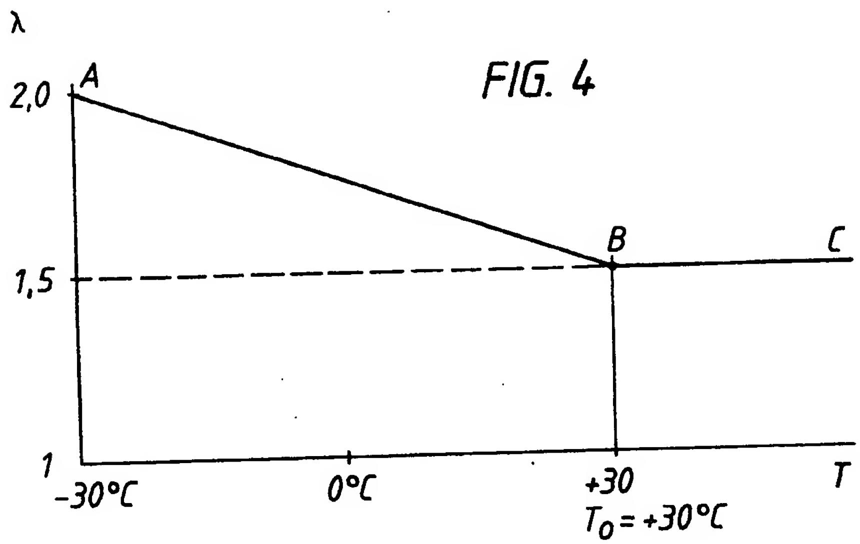

FIG. 4

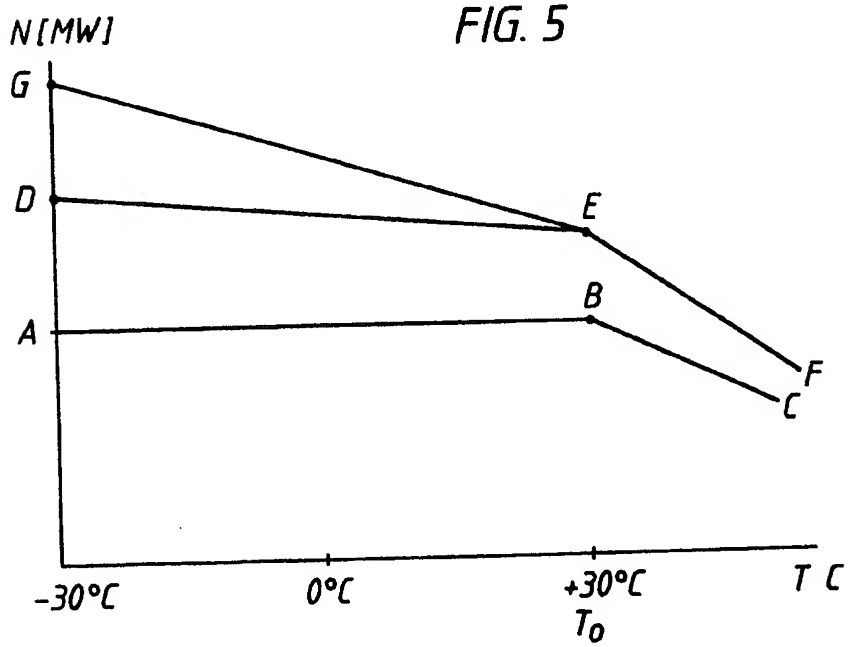

FIG. 5

SPECIFICATION

Combined gas and steam turbine plant

Technical Field

This invention relates to a method of operating a combined gas turbine and steam turbine plant of the kind in which gas for the gas turbine and steam for the steam turbine are generated in a common fluidized bed combustion chamber. The invention also relates to plant operated by the method.

In a plant of the above-mentioned kind, combustion air is supplied to the combustion chamber by an air compressor, and combustion takes place under pressure in the fluidized bed, from which the combustion gas is led to one or more gas turbines. In the fluidized bed there is at least one cooling coil in which steam is generated for supplying one or more steam turbines.

In such combined plants the cooling effect of the cooling coil(s) is substantially consant and can be regulated only with difficulty. On the other hand, the flow of air from the compressor supplying the combustion air rises with falling ambient temperature because of the increase in the viscosity of the air which then occurs. With falling air temperature an increased quantity of combustion air is thus made available. If attempts are made to utilize this available air by feeding more fuel into the combustion chamber, while maintaining an optimum excess air factor, the temperature of the fluidized bed will rise to an impermissible level. The most obvious method of limiting the bed temperature is to maintain it constant by increasing the excess air factor as the fuel supply increases. However, this method of regulation implies that the combustion efficiency is reduced, because of the increased excess air, that the combustion capacity of the combustion chamber is not utilized to the full at a low ambient temperature, and that maximum power cannot be obtained from all the turbine units of the plant at a low ambient temperature.

The present invention aims to provide a method of operating a combined gas-steam turbine plant, in which it is possible to utilize all the turbine units of the plant maximally even at temperatures below the design temperature (T_o). By the design temperature is meant the highest ambient temperature at which a certain stated power is to be obtained in a gas turbine. Normally the design temperature is about +30°C.

Disclosure of Invention

According to one aspect of the invention, a method of operating a combined gas turbine and steam turbine plant, in which gas for the gas turbine and steam for the steam turbine are generated in a common fluidized bed combustion chamber and in which the combustion chamber is designed so that, at a predetermined ambient temperature, it supplies to the gas turbine a quantity of gas that gives full power utilization of the turbine, comprises the steps of increasing the fuel supply to the combustion chamber when the ambient temperature falls below said predetermined value and gives rise to an increased excess air factor in the combustion chamber, and simultaneously regulating the temperature of the fluidized bed in the combustion chamber by injecting water or water vapour into the bed and thus preventing an impermissible increase of the bed temperature due to the increased fuel supply.

By employing the method in accordance with the invention, the mass flow through the gas turbine and thus also the power are increased, on the one hand by the increased fuel supply, and on the other hand by the water or water vapour supplied to the bed. The increased gas flow also gives a somewhat increased amount of steam generation, so that the steam turbine power is also increased somewhat.

According to a further aspect of the invention, a power plant comprises a combustion chamber, means for supplying fuel to said combustion chamber, means for creating a fluidized bed in said combustion chamber wherein said fuel is consumed by an excess of combustion air to produce combustion gas, cooling means within said combustion chamber for cooling said fluidized bed by generating steam within said cooling means, at least one gas turbine driven by the combustion gas from said combustion chamber, at least one steam turbine driven by steam from said cooling means, means for injecting water or water vapour into said fluidized bed, a first transducer for determining the excess air factor in said combustion chamber, a signal processing member which compares the actual value of the excess air factor measured by said first transducer with a desired value, a regulating device for regulating said fuel supplying means in dependence on the difference between the actual and desired values of said excess air factor, a second transducer for determining the temperature of said fluidized bed, a further signal processing member which compares the actual value of the bed temperature with a desired value, and means for regulating said water or water vapour injecting means to effect injection of water or water vapour into said fluidized bed when the actual value of the bed temperature exceeds the desired value.

In use of the method and plant in accordance with the invention, increased air supply to the combustion chamb r, caused by a decreasing ambient temperature, gives rise to an increase in th fuel supply to the combusti n chamber in such a way that the excess air factor λ is maintained substantially constant near the lowest permissible valu λ_{min}. The value of λ_{min} is determined by the risk f corrosion of the steam gen rating m ans in the fluidized bed. Th excess air factor can be xpressed as

$$\lambda = \frac{G}{m_o \cdot B},$$

wherein G = available air quantity (kg/s), m_0 = air quantity in kg required to incinerate 1 kg of fuel, and B = fuel quantity (kg/s).

The lowest permissibl value λ_{min} is tested and is dependent on the design of the combustion chamber, the fuel, the bed material, etc. Usually, $\lambda \geq 1.5$.

The water or water vapour injected into the fluidized bed may contain fuel. For example, pulverized coal or peat powder can be suspended in water in the form of a slurry and be introduced into the fluidized bed through nozzles made for this purpose.

Brief Description of Drawings

The invention will now be described, by way of example, with reference to the accompanying drawings, in which,

Figure 1 is a schematic view of a power plant,

Figure 2 is a schematic sectional view of the combustion chamber of the power plant of Figure 1,

Figure 3 is a diagram of the temperature of the fluidized bed in the plant of Figure 1,

Figure 4 is a graph showing the relationship between the excess air factor λ in the combustion chamber and the ambient temperature when the method of the invention is not employed, and

Figure 5 is a graph showing the relationship between the ambient temperature and the power obtainable from the plant.

Description of Preferred Embodiments

The plant shown in Figure 1 has a gas turbine unit comprising a high pressure turbine 6, which drives a high pressure compressor 5, a low pressure turbine 7, connected in series with the high pressure turbine, which drives a low pressure compressor 8, and a power turbine which drives a generator 19. A starter motor 10 is connected to the high pressure turbine 6. In a conduit 11 between the low pressure compressor 8 and the high pressure compressor 6 there is an intermediate cooler 12. The numeral 1 designates a pressure vessel which, as shown in Figure 2, surrounds a combustion chamber 2 containing a fluidized bed 3. The bed 3 contains a tubular coil 4 which is surrounded by the bed material. The high pressure compressor 5 is connected to the pressure vessel 1 by a conduit 14. The combustion chamber 2 is connected on its outlet side to the high pressure turbine 6 by a conduit 15. Between the conduits 14 and 15 there is a conduit 16 with a valve 17, through which compressor air may be mixed with the combustion gas from the chamber 2, in order to regulate the power of the plant. The high pressure turbine 6 and the low pressure turbine 7 are interconnected by a conduit 18. The low pressure turbine 7 is connected by a conduit 20 to the power turbine 13.

The plant has a steam turbine unit comprising a steam turbine 21 which drives a generator 22. Condensate from the condenser 22 of the turbine 21 is pumped by a feed water pump 23 through a conduit 24 to a feed water heater 25 and is then conducted through a conduit 26 to the coil 4 in the combustion chamber 2. Steam generated in the coil 4 is supplied to the turbine 21 through a conduit 27. Heat for the feed water heater 25 is derived from the exhaust gas from the turbine 13, which is led to the feed water heater 25 by a conduit 28.

The combustion chamber 2 divides the pressure vessel 1 into two separate spaces 30 and 31. Compressed air from the high pressure compressor 5 is supplied to the lower space 30 and is injected through nozzles 32 into the combustion chamber 2 and maintains the bed material in the bed 3 in fluidized condition. Fuel, for example fuel oil, is supplied to the fluidized bed through a conduit 33 from a tank 50, the supply rate being regulated by a regulating device 51 and a valve 52 in dependence on the excess air factor λ. A transducer 53 measures the actual excess air factor, and this measured value is compared with a desired value in a signal processing member 54. The difference between the actual value and the desired value is supplied to the regulating device 51 for regulating the fuel supply. If, instead of fuel oil, coal is used as the fuel fed to the bed 3, the regulating device 51 is used to regulate worm conveyors, for example, for feeding the coal to the chamber 2.

A pressurized water container 34 communicates, via a conduit 35 provided with a regulating valve 36, with nozzles 37 through which water can be injected directly into the bed 3. Evaporation of this injected water cools the bed 3. The water injection is regulated in dependence on the temperature of the bed 3, which is sensed by a transducer 38. The latter supplies a signal to a regulating device 40 via a line 41 and a signal processing member 42. In dependence on this signal, the device 40 regulates the valve 36 and thus the quantity of water that is injected into the bed 3. The transducer 38 may be positioned in or above the bed 3, since combustion gas leaving the bed 3 has approximately the same temperature as the bed.

A high efficiency in a combined gas-steam plant of the kind described, with combustionin a fluidized bed at elevated pressure, for example 10-16 bar, is one reason for the great interest in such a plant. A total system efficiency of over 40 *per cent* may b attained. Anoth r advantage is that combustion may tak place at a low temperature, for xample from 800° to 850°C, thus avoiding the producti n f ash in molten form. Ash particles acc mpanying the combusti n gases from the bed 3 are "dry" and therefore have no tendency to adhere to cleaning plant of, for example, the cyclone type. A cleaning which is sufficiently efficient for gas turbines and with insignificant risk of deposition on turbin blades is obtained. A further advantage is that sulphur in th fuel may react in a "dry" manner with a suitably chosen bed material, for exampl d l mite, and be absorbed by this material with th formation of gypsum, which can be removed together with ash from the fuel and consumed bed material. The emission of sulphur compounds with the flue gas from the

plant can thus be prevented. A particularly great advantage is that coal may be completely incinerated at temperatures as low as 800° to 850°C.

The fact that the temperature in the fluidized bed 3 must be held within close limits involves certain problems, which may however be eliminated by employing the method according to the invention. Referring to Figure 3, the temperature of the bed 3 should be maintained within the interval A-B. Within the interval B-C, combustion may be maintained but the absorption of sulphur and turbine power is reduced and the efficiency decreases. Above the level A, ash melts and may form lumps which clog the air and fuel nozzles or which may form droplets which accompany the combustion gas and which are deposited in the cleaning plant and on turbine blades. When the ambient temperature drops below the design temperature T_o, and the viscosity of the air and thus the mass flow through the compressors increase, the amount of oxygen which is available for combustion is increased. This oxygen can only be utilized to a very small extent for combustion of an increased amount of fuel if the cooling of the bed cannot be increased. The cooling effect of the steam coil is largely constant, and with increased combustion this results in the temperature of the bed increasing rapidly to an impermissible level. The excess air factor rises in a manner illustrated in Figure 4. The vertical axis indicates the excess air factor λ and the horizontal axis indicates the outside air temperature T. The design temperature $T_o = +30°C$. At the design temperature, $\lambda = 1.5$. When λ is lower than 1.5, the atmosphere in the bed assumes a reducing character and corrosion appears on tubes in the bed. $\lambda = 1.5$ is thus the lowest excess air factor that may be permitted. Without increased cooling, the supply of fuel cannot be increased in proportion to the amount of oxygen which is available at temperatures below T. The value of λ rises as indicated by the unbroken line A-B. At temperatures above T_o, the fuel supply must be reduced in order that λ should not fall below, for example, $\lambda_{min} = 1.5$. Reduced power is obtained both in the gas turbine unit and in the steam turbine unit.

Figure 5 shows the power delivered by the power plant, that is, the output power from the steam turbine 21 and from the power turbine 13 of the gas turbine unit. The steam turbine 21 supplies a substantially constant power between −30°C and +30°C, as shown by the curve AB. After that, the power decreases with increasing ambient temperature, as shown by the curve BC. The power gas turbine 13 delivers a power which is the difference between the curves DEF and ABC in the case where the method according to the invention is not employed in the operationof the plant. When the ambient temperature drops below the design temperature $T_o = +30°C$, the power is increased somewhat because of the increased air mass flow. Above T_o the power drops because of the reduced amount of oxygen available for combustion, and the fuel supply has to be reduced for λ not to drop below the permissible value. When, on the other hand, the method according to the invention is employed in the operation of the plant, the power turbine delivers a power which is the difference between the curves GEF and ABC. The additional power, which is obtained by employing the method according to the invention, is the difference between the curve parts GE and DE. This additional power is obtained because the evaporation of the water supplied to the bed cools the bed and makes possible an increased supply of fuel at an unchanged bed temperature. The increased mass flow through water and fuel supply and the increased energy supply through increased combustion result in the increased output power.

CLAIMS

1. A method of operating a combined gas turbine and steam turbine plant, in which gas for the gas turbine and steam for the steam turbine are generated in a common fluidized bed combustion chamber and in which the combustion chamber is designed so that, at a predetermined ambient temperature, it supplies to the gas turbine a quantity of gas that gives full power utilization of the turbine, which method comprises the steps of increasing the fuel supply to the combustion chamber when the ambient temperature falls below said predetermined value and gives rise to an increased excess air factor in the combustion chamber, and simultaneously regulating the temperature of the fluidized bed in the combustion chamber by injecting water or water vapour into the bed and thus preventing an impermissible increase of the bed temperature due to the increased fuel supply.

2. A method according to claim 1, wherein the water or water vapour is supplied in such an amount that the excess air factor and the temperature of the fluidized bed are maintained substantially unchanged with increased fuel supply to the combustion chamber.

3. A method according to claim 1 or claim 2, wherein the water or water vapour supplied to the bed contains suspended fuel.

4. A power plant comprising, a combustion chamber, means for supplying fuel to said combustion chamber, means for creating a fluidized bed in said combusti n chamber wh rein said fuel is consumed by an excess of combusti n air to produce combusti n gas, cooling means within said combustion chamber for co ling said fluidized bed by generating steam within said co ling m ans, at least one gas turbine driven by the combusti n gas from said combustion chamber, at least one steam turbine driv n by steam from said co ling means, means for injecting water or water vapour into said fluidized bed, a first transducer for determining the excess air fact r in said combustion chamber, a signal processing member which compares the actual value of the excess air factor measured by said first transducer with a desired valu , a regulating device for regulating said fuel supplying means in dependence on the difference betwe n the actual and desired values of said excess air factor, a second transducer for determining the temperature of said

fluidized bed, a further signal processing member which compares the actual value of the bed temperature with a desired value, and means for regulating said water or water vapour injecting means to effect injection of water or water vapour into said fluidized bed when the actual value of the bed temperature exceeds the desired value.

5. A power plant constructed and arranged substantially as herein described with reference to, and as illustrated in, Figures 1 and 2 of the accompanying drawings.

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